THE NEED TO PRESERVE NUCLEAR FUELS AND MATERIALS KNOWLEDGE

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Abstract

The demand for nuclear power will likely substantially increase in this century. Developing countries are already including new nuclear plants as an important part of their mix of energy generators. The energy shortage in the United States coupled with the recent improvements in the economic competitiveness of nuclear power is causing a reevaluation of the nuclear power enterprise. Even more importantly is the growing concern over CO_2 emissions from fossil fuel combustion, the curbing of which could increase the price of the coal option still further. Nuclear energy reduces the CO_2 burden directly by displacing fossil energy generation of electricity. In the future, the contribution of nuclear energy to the climate change problem may be even greater if nuclear energy is used for hydrogen generation in the transportation sector.

Summary

With a reasonable projected growth of nuclear power, the world's supply of U^{235}, which can be practically recovered, will be exhausted by mid-century. Therefore, the deployment of the fast breeder reactor to convert the enormous supplies of uranium and thorium to fissile material is inevitable. The question is whether the fast breeder reactor and the associated reprocessing will be ready for deployment when needed. Presently, only Japan and Russia have active programs, all others being already closed or placed in the process of closure. A review and current status of fast breeder reactor development will be presented in an attempt to address this question.

Most believe that fast breeder reactors and their supporting development and confirmation programs will be necessary within a few decades. Thus, the issue of having the right information at that time, to avoid reinventing the wheel, becomes an issue of preserving that information we now possess. In turn this includes gathering pertinent information that might exist only within the minds of aging and retiring experts as well as accumulating reports, data and samples. Then the information must be stored in an easily accessible and searchable form; and maintained over a long time during which management, hardware, software, and priorities are likely to change.

Some of this work is being done in other technical areas but in the fast reactor field, the preservation programs are limited to benchmarked data and published reports. There are no programs to gather tacit information, material samples or technical failures that provide the basis for development decisions. We summarize the existing state of affairs and make some suggestions for ensuring the success of fast reactor development at a time when they are needed to obviate diminishing fuel supplies in the future.

Introduction

The incredibly high energy density of nuclear reactor fuels gave the metallurgist (or the more recent designation of the profession, materials scientist) great challenges from the first discovery of nuclear fission. High temperatures and new combinations of fuel-to-cladding and cladding-to-coolant interfaces created a number of compatibility concerns. Soon radiation damage effects appeared that compounded the challenges. Many metal fuel alloys were studied, which were quickly followed by a large number of ceramic combinations of fuel. Along the way combinations of metals and ceramics and combinations of ceramics were investigated as dispersion fuels. A variety of bonding media was used: including mechanical bonds to the cladding, liquid metal, and gas bonding. The coolants likewise varied from water, molten salt, liquid metal, to gas.

Fuel and coolant choices were coupled with the selection of absorber, reflector, moderator, component, and structural materials. All fuels and materials selections were made to meet the objectives of the reactor. Most objectives for a reactor concept included the highest possible coolant-outlet-temperature for the best thermal steam efficiency and the highest possible fuel burnup for fuel economy. Almost always a compromise had to be made between the two. In addition, fast reactors fuels were also designed to accomplish certain breeding objectives.

For half of a century material scientists have been constantly studying and improving nuclear reactor fuels. Coolant-cladding compatibility problems never emerged as significant problems, even though a great deal of effort was spent investigating these potential concerns. This may not be the case with lead and lead alloy coolants. However, coolant-fuel compatibility upon cladding breach was a more significant problem. Metallic fuel and water were not compatible, and oxide fuel and liquid sodium coolant reacted to form a lower density product that aggravated the initial cladding breach. In general, not many fuel systems lent themselves to long term operation after cladding breach.

Fuel-cladding compatibility was a significant concern in virtually every fuel system. Proper material choices based upon literature data and out-of reactor tests of course, assured compatibility between unirradiated fuel and cladding. However, once the fission reaction started and all the new fission product elements appeared, the compatibility concerns multiplied. Cesium and iodine were the most troublesome as the cause of early cladding failure in ceramic fuel systems while the accumulation of lanthanide fission products caused concern in metallic fuel systems with the appearance of lower melting phases.

Accumulation of noble fission product gases created a number of unanticipated problems. For almost all fuel systems fission product gases had to be accommodated by an increased free plenum volume in the pins. In metallic fuel systems the fission gas bubbles caused the fuel to swell because the metal matrix flows as the pressure in the fission gas bubbles increases. Without allowance for fission gas accumulation early failure could be expected in all fuel systems. For some of the ceramic fuel systems stress due to fission gas accumulation caused the fuel to fracture. When the resulting fuel shards became wedged between the fuel pellet and cladding early cladding failure also resulted.

In fast neutron spectrum reactors, with high energy and high neutron fluxes, atomic displacement damage created an array of difficult problems. The mechanical properties of all the cladding and structural materials changed dramatically. For most metals there was a loss in ductility, the hardness increased, ductile-to-brittle transition temperatures increased, creep rates were greatly increased, and for many metals irradiation swelling appeared to the extent that intolerable dimension changes occurred. The understanding of all these phenomena and the alloy development programs created to solve them consumed the time of a large fraction of materials scientists around the world.

Many of the problems described and the solutions discovered were sensitive to fabrication techniques. In addition, solution to some of the problems carried with them safety and operational implications. Thus, the nuclear industry gave birth to extremely restrictive fabrication specifications and a high level of quality assurance unprecedented in any other industry.

Status

Nuclear research and development activities in the fuels and materials area, as well as other areas, are greatly diminished today from what they were a few decades ago. The facilities in which all the experiments on fuels and materials were conducted have fallen into a state of degradation or have vanished. For example, there is no fast reactor irradiation facility in the United States. Most importantly, the researchers who worked and lived through this period of discovery and intense investigation are disappearing from the workforce.

In most industries that have survived there has been continuity from initial discovery to large-scale market penetration with a continuous flow of information and expertise from any generation of workers to the next. Thermal reactor deployment too has enjoyed a semblance of continuity on a worldwide scale. Reactor orders for new thermal reactors are again beginning to accelerate. Thus, thermal spectrum fuels and materials research has progressed with knowledge passing from one generation to the next. However, in the fast reactor area the situation is far different and without precedent.

Interest in the deployment of fast breeder reactors has come to a halt in most countries other than in Japan and Russia. Partly, this is due to proliferation concerns about the fuel cycle but mostly it is due to the lack of near term economic necessity for additional fissile material. Yet most studies indicate an exhaustion of reasonably priced uranium by mid-century. Thus, interest in the fast breeder reactor will most assuredly reappear. The questions addressed in this paper are: What will happen to the enormous amount of fuels, materials, design and operational information that was generated through 50 years of intense and expensive research and development effort? Is it sufficient to believe that it has been documented well enough in the literature that the best of it will survive and will not have to be recreated? Neither the people nor the facilities will be available to recreate the lost information even a few years from now.

In an ongoing program such as Japan, in which the JOYO program is going well and MONJU is about to be restarted there is little incentive to preserve information as must be done in the US and France, for example. This is a pity because the issue of preserving information is easier while it is being developed. Gathering past data, deciding on its relevance and creating new databases of information in a closeout program is much more difficult. In Russia, even with an ongoing program, the issue is recognized and would be addressed but for the lack of sufficient funds.

Of what data and information are we speaking?A brief review of a typical fuels irradiation experiment will illustrate the information associated with just such an experiment.

The fuel and cladding had to be fabricated according to some specifications. It may be that both the fuel and cladding were new and thus in the process of fabrication new experience and knowledge were gained. Perhaps several attempts were required to correctly produce the fuel and cladding. The failed fabrication attempts as well as the successes are all valuable knowledge. The irradiation conditions are always important. The neutron flux and temperature are either measured or calculated. The computer codes or measurement techniques are important to be able to assess the validity of the data. After irradiation, the experiment is subjected to both non-destructive and destructive examination. A great deal of data is generated, which is subsequently examined to sort out the good data. These data may be further reduced prior to open literature publication. It may be that no open literature paper exists because the experiment failed or the program was terminated from lack of funding. All the information associated with this experiment, as well as the facilities for irradiation and their specifications, could have already been discarded. However, some of it may still exist in the combination of raw data in boxes and filing cabinets, reduced data in computer data bases, internal company reports, open literature publications, or the in the minds of the scientists and engineers associated with the experiment.

Much of the information is vulnerable to loss, if it hasn't been lost already. Obviously, an individual's personal experiences are lost when he leaves the workplace. This experience extends to knowing where to look for information as well as what information is valuable and what is not. Information that is stored in boxes and filing cabinets has and will be discarded in a specified time. Even if it hasn't been discarded it is just as damaging not knowing that the information exists or not having a road map for items of interest. Information on a computer database is a step better, but is still vulnerable to loss. Unless the information on a database is stored under a credible quality assurance program the data are always suspect. Further, the database must have a reasonable manual so the database can be queried properly. Finally, the computer technology is changing so rapidly that the hardware and software to use the database may not exist after a decade or two.

In addition, it is necessary to review the entire fast reactor technology beyond the fuels area to ensure that the whole of the essential fast reactor development is captured and the fuel data is placed in context. For example, fuel information may only be of partial value if decisions made on core assembly design and its seismic behavior during operational configurations were not also available, since the safety case is made on the fuel performance in off-normal physics spectra during seismic conditions. This US information is presently only encompassed by facility design descriptions while the actual seismic response data may have already been lost.

There may be some doubt in the minds of young scientists that a problem of knowledge loss exists and this doubt may extend to those in governmental funding positions with little experience about past programs. However, in the authors' experience hardly a week passes where a search is not initiated to find fast reactor fuels and materials information. This is often of use to a related technology such as the work in progress on the accelerated transmutation of fission products and actinides.

Similarly, for example, information on sodium technology is still required and has a present commercial value in large solar power systems.

Some fast reactor information is being preserved under programs run by the International Atomic Energy and Nuclear Energy Agency (IAEA/NEA) and by the Department of Energy's Office of Scientific and Technical Information (OSTI.) These programs encompass the gathering of explicit documents and actual data from successful experiments, which have been benchmarked. Very little tacit information (that contained within the minds of retiring experts), or design information, or material samples is being captured currently.

Is it worth spending a fraction of what it cost to generate the original information on preserving the most important of it? We feel it is, because to restart a program of development of such a technology from scratch would be even more expensive in the future.

The United States nuclear weapons establishment believes it is necessary to preserve critical information since they are in danger of losing information for much the same reasons that fast reactor technology is losing information. The cessation of nuclear weapons testing came coincidentally with the aging of the workforce. It was recognized that as the scientists and engineers retired not enough was being done to capture their years of experience. As is true in the fast reactor technology, there was no perceived need to pass their knowledge on to a new generation. This problem was identified by a congressional study as a national security concern. Therefore, the United States national laboratories involved in weapons programs were directed to rectify this situation. A number of techniques were put in place to recover and preserve the information. Retired and retiring staff were video interviewed often two or more at a time to stimulate one another in the extraction and gathering of valuable experience. A preplanned format was used in all interviews. Also key staff was asked to document the areas they perceived to be critical. Some of this information was included in special courses taught to young and promising engineers and scientists. Their work is far from over, yet there is much to be learned that could equally be applied to the preservation of fast reactor fuels and materials knowledge.

Other nations have similar programs: BNFL plc, for example, also employs "smart" interviewing to gather tacit, rather than explicit, information from retiring employees where a commercial reason exists. A national laboratory, however, has to act in the nation's interests within its best judgement of what will be needed and when.

Possible Solutions

In November 2001 the International Atomic Energy Agency will hold a consultancy to consider the problem of knowledge loss over all areas of fast reactor technology, with fuels and materials issues included. The consultancy is in response to a general understanding that action must be taken soon. Experts from all the countries that have been involved in fast reactor research and development will begin the work of determining what information should be preserved, how it should be preserved, what funds are needed, and from where the funds to do the work might come. The funds are not small because besides gathering varied information there is also the technical issue of maintaining it for 50 years in the face of software and hardware that become obsolete on a much shorter time scale.

Building upon the 'smart' interviewing techniques used by the Defense Department and by commercial organizations such as BNFL plc, a process which extends the extraction of expertise of retiring scientists and experts is proposed. It includes a direct transfer of knowledge to the younger generation at the same time as the information is gathered. The following scheme could yield significant results if conducted within the next few years.

- Assemble at the same time about double that number of young and intelligent engineers and scientists aspiring to be nuclear fuel experts.

- An agenda should be derived that contained the main subjects to be covered in the ensuing discussion but in not much detail. For example, mixed oxide fuel and fabrication might be an agenda item. The oxide fuel expert(s) would lead the discussion and would have the responsibility of focussing on real information and expertise rather than on reminiscences.

- Once the meeting progresses there would be a great deal of cross stimulation and perhaps some good debate and argument.

- The entire week would be video taped.

- Pairs of young engineers and scientists would be assigned to take copious notes in particular areas of discussion. Questions would be limited to points of clarification.

- After the week of discussion with experts the young scientists and engineers would have the responsibility of producing a document that captures discussions. Their notes and the video would be used as aids in the preparation of the document(s).

- The summary document(s) would then be cycled back to the experts for editing.

Such a meeting would be expected to yield information that hasn't been published or is difficult to find. Discussions on the rationale why some paths were rejected and others pursued would be encouraged. Subtle fabrication techniques and design decisions could be explored. Failures that were never published could be captured. Furthermore, in the process of producing such documents, which could be used for teaching and future reactor development, a number of young engineers and scientists would receive a good start on their own education.

Conclusion

We have identified a concern that unless something is done now, information needed to use the fast reactor option in the future will not be available. The serious consequences of huge additional costs for regenerating information coupled with years of delay are recognized by experts in a number of countries and international agencies. We have proposed one solution to the gathering of tacit information in the minds of aging experts and coupled that with a direct transfer to young engineers and scientists. Similar proposals need to be developed on an international basis and funds found to carry out the work in those countries that have so valuably contributed in the past decades to existing fast reactor, and particularly fast reactor fuels' information. Meetings at Reno, Nevada, this year and a following IAEA workshop will start the work.